Briefing notes on the CIRCE coastal case studies: the Gulf of Valencia

Summary

- *Within the Gulf of Valencia (Spain), the Ebro Delta and Cullera Bay are presented as examples of coastal features subject to a range of environmental pressures and vulnerable to the impacts of climate change.*

- *The Ebro River has experienced an appreciable reduction in flow due to greater freshwater abstraction. Negligible sediment is transported by the river to the delta due to lower flows and the construction of dams. As a consequence, the delta has experienced increasing rates of coastal erosion, subsidence and a decline in water quality. Sea-level rise threatens to accentuate these environmental problems and could cause salinisation, while an increase in wave storminess would accentuate erosion of the coastal fringe.*

- *Cullera Bay receives high concentrations of nutrients from the River Júcar and a marine outfall at Cullera and consequently suffers from problems of coastal pollution. Warming of sea-water due to climate change could accelerate eutrophication and further degrade water quality in the bay with deleterious effects to the natural ecosystem. A rise in sea level could further degrade the environment through salinisation and coastal erosion.*

1. The Ebro Delta

1.1 Physical and socio-economic characteristics

Geography:
The Ebro River (Figure 1) crosses the northeast of Spain with an estimated length of 930 km and a river basin comprising approximately 85,632 km^2 (Mösso *et al.*, 2008), which is about 16% of the surface of Spain. It terminates at the Mediterranean Sea, forming a delta with the shape of an arrowhead (Figure 2). The delta has two littoral spits: the *Punta del Fangar* to the north and the *Trabucador Bar* and the *Punta de la Banya* to the South. The Ebro Delta has an estimated surface of 320 km^2 and is divided by the river into two hemi deltas. Some 77% of the Ebro Delta is used for agriculture while the remainder comprises natural areas of beaches, marshes and lagoons.

Climate:
The region has a Mediterranean climate with temperatures seldom higher than 35ºC or lower than 0ºC. The annual average temperature is 16.2ºC, with a monthly maximum average of 24.2ºC in August and a minimum of 9ºC in January. The annual aver-

age rainfall is 530 l/m[2].

Winds:
In the Ebro delta area there are four prevailing winds: NE (*gregal*), E (*llevant*), SW (*garbí*) and NW (*mestral*). The prevailing winds during the summer are from the S and SW direction, although the strongest winds come from the E. In the winter, winds blow more frequently from the NW.

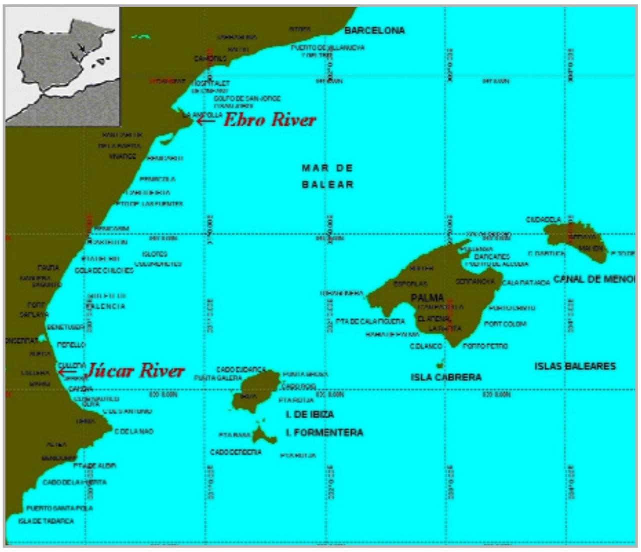


Figure 1: Location map for the Gulf of Valencia case studies: The Ebro Delta and the Cullera embayment

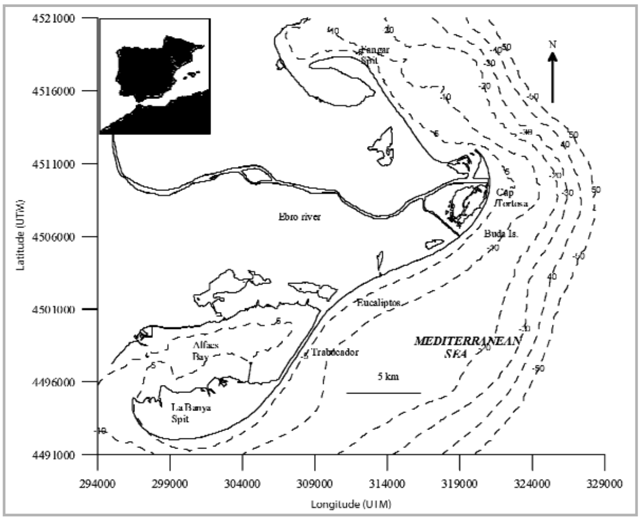


Figure 2: The Ebro Delta

Waves:
Incident waves on the Ebro Delta come from three general directions: E-NE, S and NW. The wave climate of the area has a well-defined seasonal structure with three stages: A stage of low energy (June to September) with smaller wave heights and shorter wave periods (S direction); An energetic stage (October to March) with larger wave heights and longer wave periods (E and NW dominate) and; Two stages of transition, one of decreasing energy (April to May) and one of increasing energy (at the end of September). In the transition stages, wave heights have intermediate values and waves propagate from three main directions (E, S and NW). The annual average significant wave height (Hs) and mean period (Tz) are 0.75 m and 3.9 s respectively, while the maximum peak period (Tp) during storms has a magnitude of about 11 s.

Tides:
Consistent with the Mediterranean Sea as a whole (with the exception of the northern part of the Adriatic Sea), the Ebro Delta is a microtidal environment. The maximum range of the astronomical tide is 0.25 m, with an average value of 0.16 m (Sierra *et al.*, 2002; 2004). The meteorological tide (storm surge) is a component as important (or even more important) as the astronomical one, and the maximum sea-level rise initiated by storm surges is about 1 m.

River discharge:
During the period 1960-90, the annual average discharge of the Ebro River (measured at Tortosa, 44 km from the river mouth) was 424 m^3/s (Sierra *et al.*, 2002; 2004). Mean monthly values show a maximum in February (662 m^3/s) and a minimum in August (135 m^3/s). However, for the last decade of this period (1980-90) the average values were lower: 300 m^3/s for the annual average; 461 m^3/s for the monthly average maximum; and 119 m^3/s for the monthly average minimum. In recent years, the Ebro has experienced an appreciable reduction in flow, due to increasing hydraulic exploitation.

Sediment transport:
The total amount of sediment transported by the Ebro River as suspended load (fine sand) is in the order of several thousand tons per year, but the washed load (clay and mud) transported is in the order of 100,000 or 150,000 tons per year. In contrast, sediment retained by river dams ranges from 15 to 20 million tons per year (Palanques and Drake, 1987).

1.2 Justification

The Ebro Delta is a valuable example of the vulnerability of deltaic areas of the Mediterranean to climate change (Sánchez-Arcilla *et al.*, 2007), and the complicated interactions between socio-economic pressures (abstraction of river and groundwater for agricultural and domestic purposes) (Mösso *et al.*, 2003), environmental pressures (subsidence, erosion and salinisation), and the consequences of climate change (sea-level rise and wave storminess). A wide range of climate and marine data are available for the region (Section 2.6) and a wide circle of stakeholders and decision makers have been established (Section 2.5).

1.3 Key research issues

The main coastal problems identified for the Ebro delta are related to erosion, subsidence, and water quality. Erosion of the delta is largely due to the reduction of coarse sediment supply from the river. Subsidence (lowering of the entire deltaic area) is largely due to natural or enhanced compaction (e.g., from the reduction of fine sediment supplied by the river, or pumping from groundwater aquifers) and sea-level rise. The river is highly regulated, thus water quality is closely related to the variability in river discharge. In the future, localised torrential rain may play an important role in water quality. The present threats of climate variability identified for the Ebro delta are:

i) Sea-level rise

ii) Wave storminess.

Sea-level rise could accelerate erosion, a problem compounded by subsidence of the deltaic body. Sea-level rise would also affect salinisation through the deltaic body and river course. Wave storminess would mainly affect erosion of the outer coastal fringe, and these effects would be further compounded through subsidence of the deltaic body.

1.4 Key areas of integration

The following are key impact pathways for integrating impacts of climate change in the Ebro Delta:

- Sea-level rise and subsidence – accelerated rates of erosion – degradation of coastal fringes and natural ecosystems.

- Sea-level rise and subsidence – salinisation – reduction in agricultural production and a reduction in the availability of drinking water.

- Wave storminess and subsidence– accelerated rates of erosion – degradation of coastal fringes and natural ecosystems.

1.5 Regional stakeholders, policy makers, institutions

List of end users / stakeholders for the Ebro Delta:

- Ebro River Authority (Confederación Hidrográfica del Ebro).

- Institute for the Development of the Ebro Region (Institut pel Desenvolupament de les Comarques de l'Ebre).

- Tarragona Coastal Branch, Spanish Ministry of Environment (Demarcación de Costas de Tarragona, Ministerio de Medio Ambiente).

- Regional Ministry of Territorial Policy and Public Works (Departament de Política Territorial i Obres Públiques).

- Regional Ministry of Agriculture, Nourishment and Rural Action (Departament d'Agricultura, Alimentació i Acció Rural).

- Regional Ministry of Environment and Housing (Departament de Medi Ambient I Habitatge).

1.6 Data availability

Information available for the Ebro Delta:

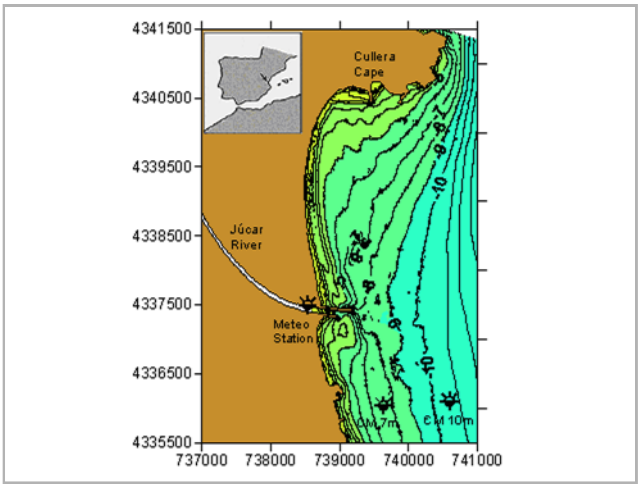
- Marine climate data: Two wave buoys (Cap Tortosa and Tarragona) provide observed data on significant wave height, maximum wave height, mean wave period, maximum peak period, wave direction and water temperature (early 1990s onwards). SIMAR-44 data (HIPOCAS project) includes numerical simulation of significant wave height, mean wave period, maximum peak period, wave direction, wind velocity and direction and sea level; 1958-2001.
- Marine water quality data from the projects FANS and PIONEER, include current velocity, nutrients, oxygen, chlorophyll, water temperature and salinity, fluorescence, transmissivity, suspended matter and phytoplankton concentrations; 1996-2000.
- Meteorological data: Three stations in the region (Deltebre, Port de l'Ampolla, Sant Carles de la Rapita) provide observed data on wind velocity and direction, air temperature and atmospheric pressure, water temperature and sea level; 1997 onwards.
- Hydrological data: Daily mean discharge is available for the Ebro River for the period 1912-2004.

2. Cullera Bay

2.1 Physical and socio-economic characteristics

Geography:
Cullera bay and the estuary of the Júcar River (Figure 1), located on the Spanish Mediterranean coast (0º 13' to 0º 15' W and 39º 08' to 39º 12' N), comprise a shallow basin with maximum depths of around 10 m (Figure 3). The Cape of Cullera, a rocky mass that protrudes into the sea, limits

Figure 3: Location of Cullera Bay



the bay on its northern side, whereas the southern end of the bay is open. It is considered a micro-tidal environment, in which the net river and marine outfall discharges display a strong seasonal cycle. The dynamics of the bay mainly depend on local sea and weather conditions (Mestres *et al.*, 2007, Sierra *et al.*, 2007). During northerly wind storms, the northern part of this semi-enclosed area becomes seriously affected by discharged detritus from the river and marine outfall. Topographically, Monte el Oro is an important feature of the landscape north of the Júcar River, while on the southern side of the river, the landscape is relatively flat.

Winds:
The wind field of Cullera bay is highly variable (on the time scale of hours to days). Onshore winds are mainly from the W, NNW and NW while offshore winds are mainly from the ESE, E and SE. However, the wind field inside the bay is far from homogeneous. The mountain of Cullera acts as a barrier to onshore winds, causing the wind to circle the mountain and funnel through the river basin. On entering the bay, it may be deflected towards the north, enhancing surface currents and transporting the freshwater plume towards the cape (Mösso *et al.*, 2007).

Waves:
Cullera Bay is located within the Gulf of Valencia where the tidal range is approximately 30 cm (spring tide) and has a limited fetch (the islands of Mallorca, Cabrera and Ibiza are only 230, 273 and 135 km east of the bay). Therefore, tides and waves have low importance relative to the wind field. The significant wave height exceeds 1 m approximately 15-17% of the time, and exceeds 1.5 m only 2-3% of the time (Mösso *et al.*, 2007).

Tides:
Consistent with the rest of the Mediterranean Sea (with the exception of the northern part of the Adriatic Sea), Cullera Bay area is a microtidal environment. The maximum range of the astronomical tide is 0.3 m. The meteorological tide (storm surge) has the same order of magnitude as the Ebro Delta (Section 1.1).

River discharge:
The Júcar River is characterised by high concentrations of nutrients due to intensive agricultural exploitation of the river's drainage basin, and the discharge of partially treated domestic and industrial wastewater from towns upstream. River discharge and the marine outfall at Cullera, are the main sources of nutrient input for the bay. The Júcar River follows a typical Mediterranean pattern, with higher flows from October to May, and lower flows during the summer months. Mean monthly discharge varies from 4 m^3/s in July and August to 16 m^3/s in February. The velocity at the river mouth has a mean value of 6-7 cm/s. Thus, the influence of river momentum to the overall hydrodynamics of Cullera Bay is negligible except during extreme

flood events (Mösso *et al.*, 2003; 2007).

Sediment transport:
Due to extreme pressures exerted on the Júcar River flow, and a weir just 2 km upstream of the river mouth, the amount of sediment transported by the river is also negligible.

2.2 Justification

The ever-changing environment of a coastal embayment creates an ecological niche that is important for seagrass, scallops, soft-shelled clams, and as a breeding ground for commercially important offshore fish. Coastal bays are also of major importance as recreational areas. However, Cullera Bay is a typical example of a multi-source polluted coastal environment (Sierra *et al*, 2007). It receives the discharge of the Júcar River and of a shallow marine outfall. Agriculture and industry exert environmental pressure on the river basin which in turn affects the water quality of the bay. Abstraction of freshwater, which is later returned to the river loaded with pesticides and fertilizers, and discharge of partially treated wastewater from riverbank towns and industries into the lower reaches of the river, are some of the mechanisms that contribute to river pollution. These environmental pressures increase the vulnerability of the region to impacts of climate change such as sea-level rise and ocean warming.

2.3 Key research issues

The dual threats of climatic variability identified for this region include warming of sea temperatures and an increase in mean sea level. Warmer temperatures would enhance eutrophication and in turn further degrade water quality. Sea-level rise would affect river discharge and salinisation, similar to the potential impacts outlined for the Ebro Delta case study.
The main issues identified for this coastal embayment are related to water quality and erosion. The chief problem is one of water quality. The high influx of tourists and visitors (by a factor of 5-10) in the summer season contributes significantly to the coastal economy but may be negatively impacted by the problems of water quality in the bay and by coastal erosion.

2.4 Key areas of integration

- Increasing sea temperature (and nutrient enrichment by industry / agriculture / settlement) – eutrophication – decline in water quality – negative impact on tourism / fishing industry.

- Rising sea level - river discharge – salinisation / coastal erosion – negative impact on tourism.

2.5 Regional stakeholders, policy makers, institutions

Stakeholders for Cullera Bay include:

- Valencia Coastal Branch, Spanish Ministry of Environment (Demarcación de Costas de Valencia, Ministerio de Medio Ambiente).

- Júcar River Authority

(Confederación Hidrográfica del Júcar).

- Regional Ministry of Agriculture, Fisheries and Nourishment (Consellería de Agricultura, Pesca y Alimentación).
- Regional Ministry of Territory and Housing (Consellería de Territorio y Vivienda).
- Regional Ministry of Enterprise, University and Science (Consellería de Empresa, Universidad y Ciencia).
- Municipality of Cullera (Ayuntamiento de Cullera).

2.6 Data availability

Available meteorological, marine and hydrological data for Cullera Bay:

- Wave buoy (Valencia): Data on significant wave height, maximum wave height, and mean wave period, 1985-2005.
- SIMAR-44 data (HIPOCAS project): Data obtained from numerical simulation, including significant wave height, wave period, maximum peak period, wave direction, wind velocity and direction and sea level; 1958-2001.
- Water quality data (ECOSUD projects): including nutrients, chlorophyll, water temperature and salinity, suspended matter and phytoplankton concentrations. Data from different cruises between 2002 and 2003.
- Tidal gauge (Valencia): Sea level, 1992-2007.
- Júcar River discharge (Cullera): Total monthly discharge, 1911-1997.

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References:

- Mösso, C., Mestres, M., Sánchez-Arcilla, A., Sierra, J. P., González del Río, J., Rodilla, M. & López, F. (2003). River plume behaviour in the Spanish Mediterranean Coast. Hydromorphodynamic controls. *Proc. 3rd IAHR Symposium on River, Coastal and Estuarine Morphdynamics*, pp 935-945.
- Mösso, C., Sierra, J. P., Mestres, M., Cupul, L., Falco, S., Rodilla, M., Sánchez-Arcilla, A. & González del Río, J. (2007). The influence of topography on wind-induced hydrodynamics in Cullera Bay. *Journal of Coastal Research* (ISSN: 0214-8358), Special Issue 47 pp 16-29.
- Mösso, C., Sierra, J.P., Rodilla, M., Romero, I., Falco, S., González del Río, J and Sánchez-Arcilla, A. (2008). High Vertical Resolution Sampling in Density Interfaces of Estuaries and River Plumes. *Estuaries and Coasts,* In Press.
- Palanques, A. and Drake, D.E. (1987). Distribution des suspensions sur le plateau du delta de l'Ebre. *Colloq. Int. Océanologie, Ecosystèmes de Marges Continentales, CIESM,* Perpignan, 23 pp.
- Sánchez-Arcilla, A., Jiménez, José A. and Valdemoro, H. (2007). The Vulnerability and Sustainability of Deltaic Coasts: The Case of the Ebro Delta, Spain. *Managing Coastal Vulnerability*. Loraine McFadden, Robert J. Nicholls and Edmund Penning-Roswell (editors), Elseiver. 79-95 pp.
- Sierra, J. P., Sánchez-Arcilla, A., González del Río, J., Flos, J., Movellán, E., Mösso, C., Martínez, R., Rodilla, M., Falco, S. & Romero, I. (2002). Spatial distribution of nutrients in the Ebro estuary and plume. *Continental Shelf Research* (ISSN: 0278-4343), Vol 22 (2) pp 361-378.
- Sierra, J. P., Sánchez-Arcilla, A., Figueras, P. A., González del Río, J., Rassmusen, E. K. & Mösso, C. (2004). Effects of discharge reductions on salt wedge dynamics of the Ebro river. *River Research and Applications* (ISSN: 1535-1459), Vol 20 (1) pp 61-77.
- Sierra, J. P., Mösso, C., González del Río, J., Mestres, M., Cupul, L., Sánchez-Arcilla, A., Rodilla, M., Falco, S., Romero, I., González, D. & Puigdefábregas, J. (2007). Sources and sinks of nutrients and pollutants in Cullera Bay. *Journal of Coastal Research* (ISSN: 0214-8358), Special Issue 47 pp 30-38.

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